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THE EFFECTS OF RADIANT HEAT ON VARIOUS REGIONS OF THE HUMAN BODY

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THE EFFECTS OF RADIANT HEAT ON VARIOUS REGIONS OF THE HUMAN BODY†

Part I: Time Sequence of Perspiration and Skin Temperature in Various Regions of the Body Exposed to Infrared Radiation, and Especially Acclimated and Unacclimated Subjects.

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ABSTRACT: In considering the effects of radiant heat on man, the author has investigated the time sequence in which perspiration appears on the face and on equal surface areas of the thorax and abdomen, in subjects acclimated and unacclimated to locally applied infrared heat. The heat source was an electric heater (with a metal coil) at a temperature of 1040-1060°C, the incident thermal flux being equal to 0.044 $\frac{cal}{cm^2/sec}$. *The subjects exposed the chosen surface to the heat through a window of adjustable dimensions, in a shield cooled by circulating water; this shield protected the rest of the body from the heat. In unacclimated subjects, perspiration began to appear after an exposure of 180 sec, first on the abdomen and thorax and then on the face; the skin temperature was lower on the face then in the other two regions. In acclimated subjects, perspiration first appeared on the face (after 15-30 sec exposure), then on the abdomen and finally on the thorax, the skin temperature rising in the same order. The topographical order of appearance of perspiration, the lack of dependence of skin temperature on the appearance of perspiration, and the differences of times of perspiration are discussed; it is suggested that in addition to peripheral reflex mechanisms, perspiration may also be connected with central mechanisms which need not necessarily involve the anterior hypothalamus.*

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Numerous experiments have been performed in the past which indicate that the acclimation of man to elevated ambient temperatures and to intense caloric irradiation consists primarily in the ability to secrete a larger amount of perspiration [1-5], in addition to a gradual adaptation of the circulatory system [6-7], and an increase in the volume of circulatory blood and hypertrophy of the perspiration glands [8]. /293*

On the other hand, we do not know whether acclimated subjects also possess a more rapid and effective nervous regulation of perspiration. Moreover, the nerve mechanisms which are normally involved in the regulation of perspiration are still not understood completely. According to Seckendorf, Randall, et al. [9, 10], the secretion of perspiration is caused by a spinal reflex mechanism stimulated by specific receptors distinct from those which are thermosensitive [10-12], with successive development of the process of perspiration being governed by the hypothalamus [10]. On the other hand, according to Benzinger [13, 14], the thermal receptor cutaneous impulses are of secondary importance, and the perspiration is due primarily to the temperature of the hypothalamus or the blood which circulates through it.

With regard to the method of perspiration production, it has been observed in the past by Randall et al. [9, 10, 15-17] that when the organism is exposed to an elevated ambient temperature, perspiration is not produced at the same rate over the entire surface of the body [18, 19], but occurs first on the back of the foot and then in other areas in this order: the calves, trunk, forearms, and finally the face.

Since it had been shown that infrared radiation is also sufficient to stimulate perspiration [19], we decided to study the time of appearance of perspiration on the face and on equal surface areas of the thorax and abdomen, exposed to intense infrared radiation, in subjects not habitually exposed to elevated temperatures and in subjects acclimated either to elevated ambient temperatures or to intense infrared radiation, after years habitually spent working in steel mills. The problem is of particular significance in the field of industrial physiology, with particular emphasis on the metal working industry where exposure to elevated ambient temperatures or to localized infrared radiation are common.

Experimental Method /294

The experiments were performed on 13 healthy male subjects aged from 32-43, who are not acclimated, and on 11 healthy male subjects aged from 30-45, who had been exposed daily for 8-10 years

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* Numbers in the margin indicate pagination in the foreign text.

(as employees in a hot-rolling mill for producing sheet steel) to infrared radiation from the surface of the metal at 1000-1100° C, at ambient temperatures up to 50-52° C.

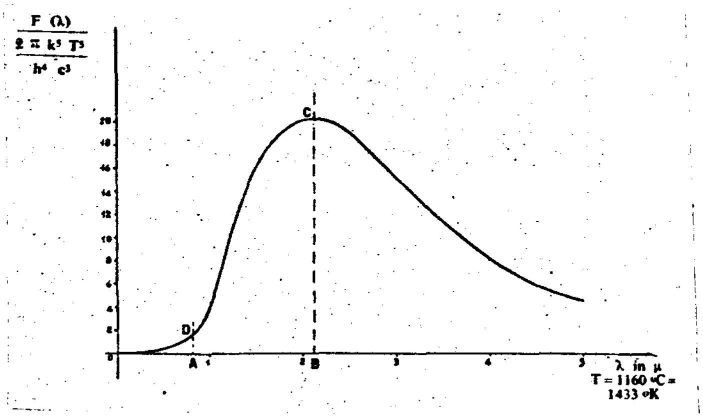

Fig. 1. Emission Spectrum of Infrared Radiation from the Heater (Absorbed in a Blackbody). The Ratio Between the Area ABCD and the Total Area Between the Curve of the Axis of the Abscissa and the Extreme Ordinate Indicates that 26% of the Radiant Energy Emitted by the Source has a Wavelength Between 0.8 and 2.2 μ.

The heat source employed in the experiments was an electric heater made of six coils of tungsten steel, 35 cm long; the wire itself was 3 mm in diameter, and the diameter of each spiral was 30 mm. The heater was kept at a temperature of 1040-1060° C by means of a special regulating pyrometer.

In Figure 1, showing the heat absorbed by a blackbody, we have plotted the quantity of radiant energy emitted per second from 1 cm^2 of the source, as a function of the wavelength between 0 and 5 μ for a temperature of approximately 1060° C.

The ratio of the area ABCD to the total area between the curve of the axis of the abscissa and the extreme ordinate indicates that 26% of the radiant energy emitted by the source has a wavelength between 0.8 and 2.2 μ. The cutaneous absorption for wavelengths between 0.3 and 4.0 μ, in the case of white skin, is 60-70% [20].

The caloric flux was measured by a calorimetric method.

The measurements were made by exposing a metal cube, measuring 10 cm on an edge, at a distance of 1.2 meters from the radiant source. The face of the cube which was turned toward the source was blackened, while the remaining forces were polished and coated with an insulating material; the cube was filled with 1000 cc of distilled water. The temperature variation undergone by the water following exposure to the heat for intervals of 30, 60, and 90 minutes was determined. In order to measure the quantity of heat radiated by the cube, we also measured the variations occurring during periods of time which were equal to and immediately followed periods of exposure.

The measurements were made under the same conditions as the /295
experiments, with the same climatic conditions being maintained: t = 26.5° C, humidity equals 46%. This was done to avoid any possible external influence.

The caloric flux was found to be 0.044 $\frac{cal}{cm^2/sec}$, obtained as the average value from a series of 144 measurements.

During the experiment, the subjects were placed 1.20 m from the source, behind a shield fitted with a window and equipped with constantly circulating water. The subject exposed the region to be irradiated by placing it against the window (whose dimensions could be varied), while the rest of his body remained completely protected. To measure the quantity of heat intercepted by the face of the subject, we calculated the projection of the surface of the face on a plane normal to the caloric radiation. To do this, we measured the surface area of a shadow cast by the subject's head, from the vertex up to a transverse plane passing through the level of the upper edge of the thyroid cartilage, behind which was placed a light source with a parallel beam. Regulating the size of the window in the shield made it possible to irradiate equal areas of the thorax and abdomen.

The skin temperature was measured with a copper-constantan thermocouple, fitted with a handle and precalibrated with a precision mercury thermometer. Production of perspiration was detected by observing the moment when grains of dry methylene blue, finely pulverized and applied to the skin by means of a piece of transparent tape, were melted by perspiration, causing a small blue spot to appear. The simplicity and high speed of this system led us to choose it in preference to other methods.

The experiments were performed in a laboratory kept at a temperature between 24 and 26°, with humidity between 45 and 55%, and in the absence of any air currents (except those generated by the infrared source).

Two tests were performed on all the subjects (or more, if the results were very different) for all the regions indicated, allowing at least four to five days to pass between tests in order to avoid any accommodation phenomena.

The oral temperature was also monitored during the measurements.

Results

The results of the study are listed in Tables 1, 2 and 3 and shown in Figures 2, 3 and 4. All of the values in the tables are the averages of results of two or more tests made on the same subject. The graphs in the figures were plotted from average data on individual subjects. An examination of the experimental data shows that in unacclimated subjects, perspiration appeared after about 180 sec of exposure, slightly earlier on the thorax (170 ± 54 sec) and on the abdomen (145 ± 44 sec) then on the face (196 ± 48 sec). With increased skin temperature, perspiration appeared on the thorax

(42.7 ± 1.26) and abdomen (42.7 ± 1.28° C) earlier than on the face (40.7 ± 0.64° C). In the acclimated subjects, on the other hand, perspiration appeared somewhat earlier on the face (48 ± 23.2 sec) than on the abdomen (69 ± 57 sec) or on the thorax (145 ± 50 sec), corresponding to skin temperatures of 38.3 ± 1.67° C on the face, 38.4 ± 2.5° C on the abdomen, and 41.2 ± 1.22° C on the thorax.

From the moment when perspiration first appeared, the skin temperature was kept constant for the entire remainder of the exposure; in the unacclimated subjects, it was kept at a level 1-1.5° C higher than for the acclimated subjects, while the sensation of local heat was noticeably subdued in all subjects. After the termination of exposure, the skin temperature diminished rapidly; after two minutes, the acclimated subjects showed stabilization of the temperature of the irradiated zone at a level which was 1° C lower on the average then was the case in the unacclimated subjects, while /296
perspiration ceased when the irradiation was terminated.

TABLE 1. SKIN TEMPERATURE OF THE FACE AND EXPOSURE TIME PRIOR TO APPEARANCE OF PERSPIRATION IN SUBJECTS

Unacclimated

Subjects		Irradiated surface cm^2	Initial temp. °C	Temp. at which perspiration occurs °C	Δ in °C	Δ %	Duration of exposure prior to appearance in sec
W.V.	(1)	408	33.8	41.9	8.1	23.9	180
R.A.	(1)	394	34.9	40.8	5.9	16.9	150
B.G.	(1)	379	34.1	41.0	6.9	20.2	240
A.R.	(1)	390	34.9	40.0	5.1	14.6	150
G.B.	(2)	383	34.7	40.1	5.4	15.5	180
V.W.	(2)	405	33.9	40.3	6.4	18.8	180
M.G.	(2)	394	33.7	40.0	6.3	18.7	120
C.G.		397	33.8	41.3	7.5	22.1	240
C.A.	(2)	375	35.1	41.0	5.9	16.8	270
C.A.	(2)	403	35.6	40.4	4.8	13.4	270
S.E.	(3)	405	34.0	41.5	7.5	22.1	210
A.L.		378	34.5	40.5	6.0	17.3	210
E.S.	(3)	407	33.4	40.3	6.9	20.3	150
Average		393 ± 12.4	34.4 ± 0.70	40.7 ± 0.64	6.3 ± 0.98	18.5 ± 3.1	196 ± 48.3

Acclimated

Subjects		Irradiated surface cm^2	Initial temp. °C	Temp. at which perspiration occurs °C	Δ in °C	Δ %	Duration of exposure prior to appearance in sec
G.G.	(2)	393	33.8	37.7	3.9	11.5	30
DL.A.	(1)	398	34.2	40.7	6.5	19.0	90
C.E.	(1)	405	34.2	40.2	6.0	17.8	60
G.A.	(1)	377	34.2	40.2	6.0	17.8	60
P.R.	(2)	383	33.3	37.2	3.9	11.7	30
T.T.	(2)	391	33.9	37.8	3.9	11.5	30
P.L.	(2)	407	34.5	38.9	4.4	12.7	60
A.G.	(2)	387	34.1	35.1	1.0	2.9	15
G.R.	(2)	390	35.0	36.7	1.7	4.8	25
E.C.	(2)	403	34.0	38.9	4.9	14.4	70
R.P.	(2)	393	34.0	38.4	4.4	12.9	60
Average		393 ± 10.4	34.1 ± 0.5	38.3 ± 1.67	4.2 ± 3.6	12.4 ± 5.0	48 ± 23.2

(1) Average of 4 tests.
(2) Average of 3 tests.
(3) Average of 2 tests.

In all of the subjects, regardless of the area irradiated, the oral temperature showed an appreciable increase after five or six minutes; after eight minutes, this increase remained at an average of 0.16° C, with extremes of 0.1° C and 0.22° C.

Discussion

Production of perspiration occurs in unacclimated subjects at various times, depending on the region irradiated. If the flux from the source is kept constant, since the temperature increase of the skin in the individual regions prior to initiation of perspiration is not proportional to the difference of the times required for perspiration, and since the latter remained practically constant during the experiment and are equal for all the regions considered and for all the subjects studied, the heat loss by conduction /297 and by radiation as well as the dissipation of heat varied from one region to another prior to production of perspiration due to the influence of "perspiratio insensibilis" and by convection by the circulation.

TABLE 2. SKIN TEMPERATURE OF THE THORAX AND EXPOSURE TIME PRIOR TO APPEARANCE OF PERSPIRATION IN SUBJECTS

Unacclimated

Subjects		Irradiated surface cm^2	Initial temp. °C	Temp. at which perspiration occurs °C	Δ in °C	Δ %	Duration of exposure prior to appearance in sec
W.V.	[illegible]	[illegible]	[illegible]	43.8	[illegible]	33.1	150
R.A.	(1)	394	33.6	42.8	9.2	27.3	120
B.G.	(1)	379	34.3	42.6	8.3	24.2	150
A.R.	(1)	390	33.1	40.4	7.3	22.0	150
G.B.	(1)	383	34.6	42.8	8.2	23.7	150
V.W.	(1)	405	32.1	43.8	11.7	33.3	150
M.G.	(2)	394	30.8	40.3	9.5	30.8	90
C.G.		397	34.3	43.9	9.6	27.9	180
C.A.		375	34.7	41.7	7.0	20.0	180
S.E.	(2)	405	33.8	43.7	9.9	29.2	300
C.A.		403	34.9	43.6	8.7	24.9	180
F.S.	(2)	407	34.5	43.2	8.7	25.2	240
Average		395 ± 11.9	33.6 ± 1.22	42.7 ± 1.26	9.0 ± 1.35	26.8 ± 4.3	170 ± 54.7

Acclimated

Subjects		Irradiated surface cm^2	Initial temp. °C	Temp. at which perspiration occurs °C	Δ in °C	Δ %	Duration of exposure prior to appearance in sec
C.G.	(1)	393	33.2	42.6	[illegible]	[illegible]	120
DL.A.	(1)	398	33.8	[illegible]	[illegible]	[illegible]	150
C.E.	(1)	405	32.1	[illegible]	[illegible]	[illegible]	150
G.A.	(1)	377	33.4	[illegible]	[illegible]	[illegible]	180
P.B.	(2)	383	33.4	40.0	6.6	[illegible]	150
[illegible]	(2)	391	[illegible]	41.7	[illegible]	[illegible]	150
[illegible]	(2)	[illegible]	[illegible]	40.7	[illegible]	[illegible]	[illegible]
E.C.	(2)	[illegible]	[illegible]	41.9	[illegible]	22.8	[illegible]
A.L.		[illegible]	[illegible]	[illegible]	[illegible]	11.8	[illegible]
Average		393 ± 11.6	33.3 ± 0.6	41.2 ± 1.22	7.8 ± 1.82	23.7 ± 5.4	145 ± [illegible]

(1) Average of 3 tests.
(2) Average of 2 tests.

On the other hand, since the absolute and percentual increase in the initial temperature for perspiration production occurred more slowly at the level of the forehead than at the levels of the thorax and abdomen, it could be concluded that the circulatory flow and the perspiratio insensibilis occurred sooner and more intensely at the forehead then in the other regions. With this difference in the temperature increase, there was a different degree of intensity in the burning sensation reported by the subjects; it was least on the face and successively greater on the thorax and abdomen.

These results indicate that the vasomotor processes and those of perspiration production show different behavior depending on the area, and that the vasodilation produced by infrared radiation can precede the occurrence of perspiration. Since the difference between the times of the occurrence of perspiration in the three regions is less than "1 σ", the average values of the time required for perspiration to occur can be listed in the order: abdomen, thorax, and face, i.e., the order previously given by Randall [15-17]; we could then confirm the existence of a mechanism of circulatory regu- /298 lation and perspiration regulation which acts in different ways on the trunk and face [21]. However, it was not possible with these subjects to determine whether perspiration was caused by spinal reflexes alone or whether it was governed by central impulses, in which case the oral temperature would be 1-2 tenths greater than the initial temperature at the moment when perspiration was produced.

TABLE 3. ABDOMINAL SKIN TEMPERATURE AND EXPOSURE TIME PRIOR TO PERSPIRATION PRODUCTION IN SUBJECTS

Unacclimated

Subjects		Irradiated surface cm^2	Initial temp. °C	Temp. at which perspiration occurs °C	Δ in °C	Δ %	Duration of exposure prior to appearance in sec
W.V.	(1)	408	33.6	43.7	10.1	30.0	120
R.A.	(1)	394	31.3	40.3	9.0	28.9	120
B.G.	(1)	379	34.5	43.2	8.7	25.2	60
A.R.	(1)	390	31.2	42.4	11.2	35.8	210
G.B.	(1)	383	35.1	44.0	8.9	25.3	180
V.W.	(1)	405	32.1	40.4	11.1	34.5	180
M.G.	(2)	394	30.4	43.2	10.0	32.8	90
C.G.		397	32.8	44.1	11.3	34.4	150
S.E.	(2)	405	32.4	42.6	10.2	31.4	150
C.A.	(2)	403	33.0	42.4	9.4	28.4	180
A.L.		378	33.8	43.2	9.4	27.7	120
E.S.	(2)	407	33.2	43.9	10.7	32.5	180
Average		395 ± 11.5	32.7 ± 4.4	42.7 ± 1.28	10.0 ± 0.92	30.5 ± 8.2	145 ± 44

Acclimated

Subjects		Irradiated surface cm^2	Initial temp. °C	Temp. at which perspiration occurs °C	Δ in °C	Δ %	Duration of exposure prior to appearance in sec
G.C.	(1)	393	30.8	35.5	4.7	15.2	30
DL.A.	(1)	398	31.5	40.6	9.1	28.8	60
C.E.	(1)	405	33.0	41.5	8.5	25.7	120
P.R.	(2)	383	33.3	38.7	5.4	16.2	90
T.T.	(2)	391	32.5	36.6	4.1	12.6	30
P.L.	(3)	407	33.6	37.8	4.2	12.5	30
A.L.	(3)	395	33.2	36.7	3.5	10.5	45
E.C.		396	32.1	41.9	9.8	30.5	195
L.A.		395	32.7	37.1	4.4	13.4	25
Average		395 ± 8.13	32.5 ± 0.89	38.4 ± 2.5	5.9 ± 1.18	18.3 ± 3.8	69 ± 57

(1) Average of 4 tests.
(2) Average of 3 tests.
(3) Average of 2 tests.

A comparison of the data for the unacclimated subjects and that for the acclimated subjects shows the extremes which can be observed for phenomena which vary the nature of the response to thermal stimuli.

In acclimated subjects, the production of perspiration always occurs much earlier ($P = 0.01$) and occurs in an order (face, abdomen, thorax) which is different from that for unacclimated subjects. This fact shows that in the acclimated subjects, the dispersion of heat by means of visible perspiration occurs sooner, in addition to the "perspiratio insensibilis", and reduces the quota of thermal energy carried to other parts of the organism by the circulatory system, thus keeping the skin at a lower temperature than that found in unacclimated subjects. On the other hand, once perspiration has /299 begun, there are no differences between the two groups, due to the fact that the temperature of the irradiated skin remains the same from the moment when perspiration begins and all through the period of irradiation, thus indicating that the capacity for local dispersion of heat (via evaporation, reflection, and circulatory convection) is equal for all the groups, being equal to the quantity of incident heat in all cases.

It is important that in the case of acclimated subjects, the perspiration is produced in each subject after 15-30 sec following the start of irradiation, i.e., in a time which is too short

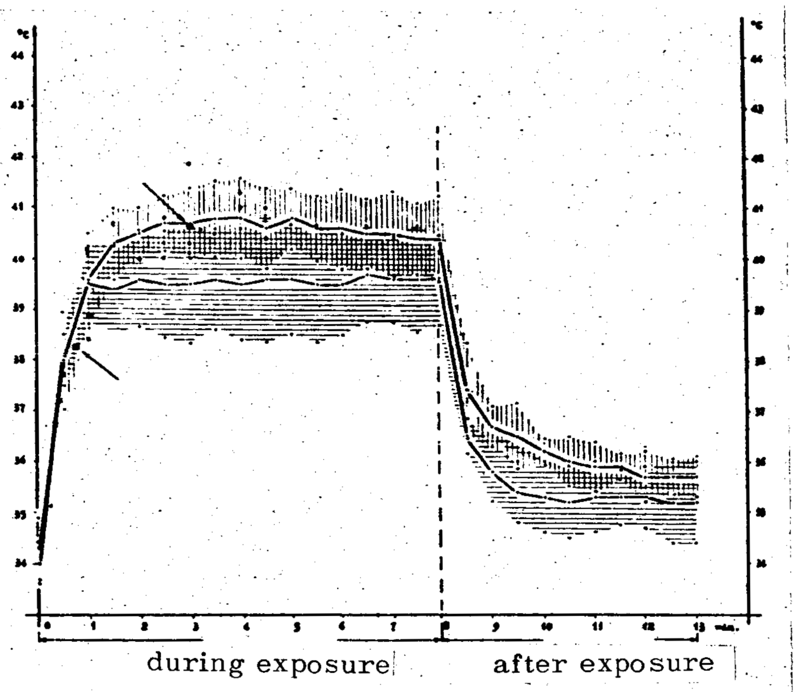

Fig. 2. Change in Average Values (and Sigma Variation) of the Forehead Temperature During and After Infrared Irradiation of the Face (Thermoflux at the Skin: 0.044 $\frac{\text{cal}}{\text{cm2/sec}}$) in Unacclimated Subjects (Upper Line) and Acclimated Subjects (Lower Line). The Crosses "+" and the "x"'s Indicate the Individual Average Values of the Production Times and the Forehead Temperature at the Time When Perspiration Begins, Respectively, in Unacclimated Subjects (Average Value for all Subjects Indicated by Upper Arrow) and in Acclimated Subjects (Average Value of all Subjects Indicated by Lower Arrow).

to produce an increase in central temperature. In these cases, it would appear less likely that the determining factor in perspiration would be only the temperature increase of the blood which circulates at the level of the hypothalamus [14], but rather that it must involve the additional participation of some other mechanism, either peripheral in the sense of the spinal reflex [9] or central, but different from the increase in the temperature at the hypothalamic region. By comparing the average values of skin temperature at the moment when perspiration begins, the values for the increases which are noted, and those for the perspiration times as listed for similar regions in the two groups of subjects, significant statistical differences can be found only in the case of the face, even though perspiration is generally produced earlier and at a lower temperature in the acclimated subjects than in the unacclimated ones, in regions other than the face. /300

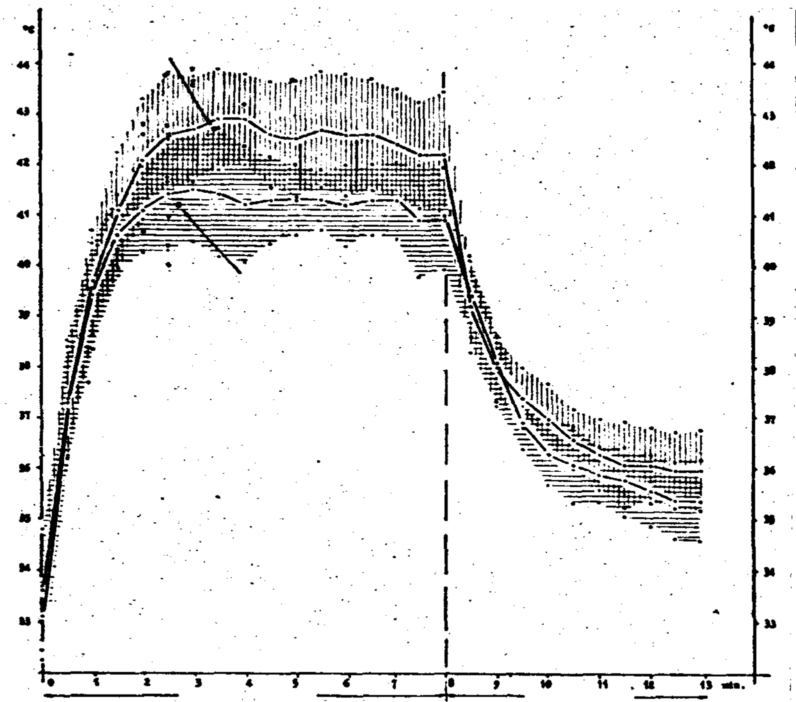

Fig. 3. Change in Average Values (and Sigma Variation) of Thoracic Temperature During and After Infrared Irradiation of the Thorax (Thermo-flux on the Skin: $0.044 \frac{\text{cal}}{\text{cm2/sec}}$) in Unacclimated Subjects (Upper Line) and Acclimated Subjects (Lower Line). The Crosses "+" and "x"'s Indicate the Individual Average Values for the Time of Occurrence of Perspiration and the Skin Temperature at the Moment When Perspiration Begins, Respectively, for Unacclimated Subjects (Average Value for all Subjects Indicated by Upper Arrow) and Acclimated Subjects (Average Value of all Subjects Indicated by Lower Arrow).

Hence, the result is that in each case the perspiration may differ from one area to the next, and can vary in different ways depending on the region, following repeated exposure to local thermal stimuli; this is an additional phenomenon besides those already /301 noted with respect to acclimation.

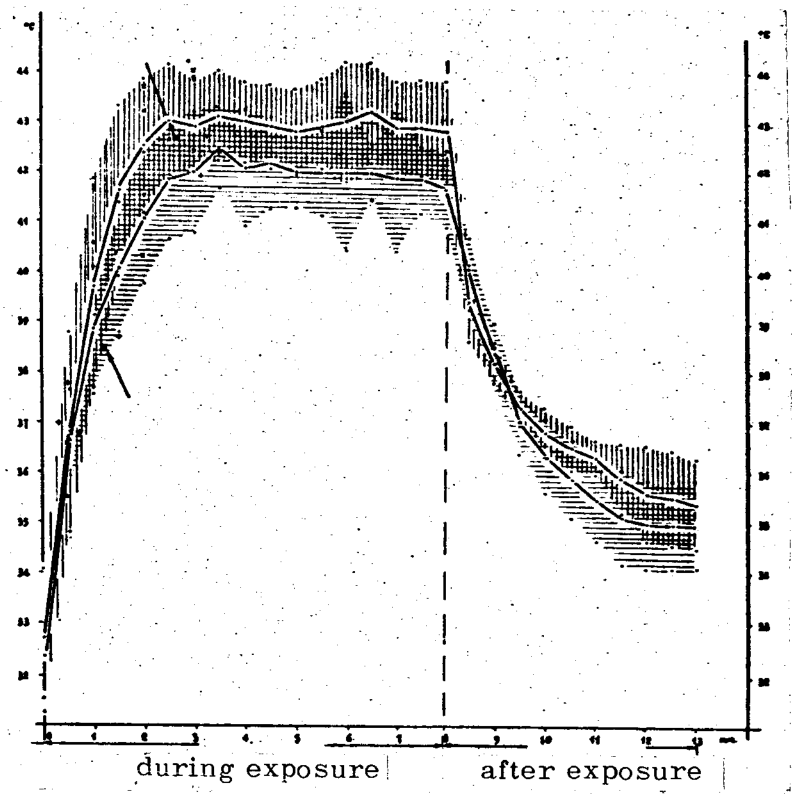

Fig. 4. Change in Average Values (and Sigma Variation) of Abdominal Temperature During and After Infrared Radiation of the Abdomen (Thermoflux on Skin: 0.044 $\frac{cal}{cm^2/sec}$) in Unacclimated Subjects (Upper Line) and Acclimated Subjects (Lower Line). The Crosses "+" and "x" 's Indicate the Individual Average Values of the Time of Perspiration and the Temperature of the Skin at the Moment When Perspiration Begins, Respectively, in Unacclimated Subjects (Average Value for all Subjects Shown by Upper Arrow) and Acclimated Subjects (Average Value for all Subjects Shown by Lower Arrow).

The higher value of the skin temperature in the region exposed during irradiation in the unacclimated subjects, moreover, can explain the occurrence of a greater intensity of subjective sensation of burning as expressed by the unacclimated subjects versus the acclimated ones. The manner in which the greater resistance of the latter to exposure to intense temperatures increases, can be attributed more to variation of the threshold of sensitivity to burning pain and to reduce stimulation of the thermal receptive nerve endings in the skin.

REFERENCES

1. Lehmann, G. and A. Szakall: Arbeitsphysiol., Vol. 9, p. 678, 1937.
2. Wenzel, H. G.: Atti del XVIII Deutscher Sportarzte Kongress (Transactions of the 18th Congress of German Sport Physicians), Amburg, Frankfurt, W. Limpert Verlag, 1957. NB p. 156.
3. Eichna, L. W., C. R. Park, N. Nelson, S. M. Horvath and E. D. Palmes: Amer. J. Physiol., Vol. 163, p. 585, 1950.
4. Lind, A. R. and D. E. Bass: Federation Proc., Vol. 22, p. 704, 1963.
5. Robinson, S. and S. D. Gerking: Amer. J. Physiol., Vol. 149, p. 476, 1947.
6. Lehmann, G.: Le Travail a la chaleur (Work under Heat), Ed. Revue de Metrologie, Paris, 1959.
7. Hellon, R. F. and A. R. Lind: J. Physiol., Vol. 128, p. 57, 1956.
8. Leithead, C. S. and A. R. Lind: Heat Stress and Heat Disorders. Cassel, London, 1964.
9. Seckendorf, R. and W. C. Randall: J. Appl. Physiol., Vol. 16, p. 796, 1961.
10. Randall, W. C., C. N. Peiss and R. O. Rawson: J. Appl. Physiol., Vol. 12, p. 385, 1958.
11. Issekutz, B., G. Hetenyi and A. Diosy: Arch. Internat. Pharmacodyn., Vol. 83, p. 133, 1950. Cited in [10].
12. Rothman, S.: Physiology and Biochemistry of the Skin. University of Chicago Press. Chicago, 1954.
13. Benzinger, T. H.: Proc. Nat. Acad. Sc. U.S., Vol. 45, p. 649, 1959. Cited in]9].
14. Benzinger, T. H.: Federation Proc., Vol. 19, Suppl. 5, p. 32, 1960.
15. Rawson, R. O. and W. C. Randall: J. Appl. Physiol., Vol. 16, p. 1006, 1961.
16. Hertzman, A. B., W. C. Randall, C. N. Peiss and R. Seckendorf: J. Appl. Physiol., Vol. 5, p. 153, 1952.
17. Randall, W. C. and A. B. Hertmann: J. Appl. Physiol., Vol. 5, p. 399, 1953.
18. Randall, W. C.: Amer. J. Physiol., Vol. 150, p. 365, 1947.
19. Kuno, Y.: The Physiology of Human Perspiration. London, Churchill, 1934.
20. Kuno, Y.: Human Perspiration. Springfield, Thomas, 1956.
21. Kuppenheim, H. F. and R. R. Heer: J. Appl. Physiol., Vol. 4, p. 800, 1952.
22. Blair, D. A., W. E. Glower and J. C. Roddie: J. Appl. Physiol., Vol. 16, p. 119, 1961.

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